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Roll to Roll Inspection Platform: Analysis of In-line Defect Detection for Flexible Substrates

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Author Note: The Roll to Roll Inspection Platform project has six interdisciplinary team members from the Watson School of Engineering and Applied Sciences of SUNY Binghamton. These six students have been members of the project from September 2018 until the end of the academic year in May 2019. The team would like to express gratitude to the advisors and key personnel. The team would like to thank Rodney Vargason and Christian Bezama who are employees of the Center for Advanced Microelectronics Manufacturing (CAMM) and have assisted the team with the project. The team would also like to thank Dr. Mark D. Poliks, the faculty advisor who has also provided funding and the Center for Advanced Microelectronics Manufacturing (CAMM) Lab for the project. Lastly, the team would like to thank Dr. Gang Sun of SunOptical Systems for his guidance and the SunOptical equipment he has provided.

Abstract: The inspection and detection process of thin film substrates determines the quality of thin films which are used in a variety of industries. The process for the Roll to Roll Inspection Platform occurs in the CAMM Lab and consists of rolls of thin films being threaded through the inspection platform, allowing defects on the roll to be detected. Through the use of the Energy Conversion Device, SunOptical Defect Sensor, Dell Computer, and Defect Detection MATLAB code, samples from each thin film substrate are taken and analyzed to determine details of any defects on the substrates. The system outputs a report with defect information displayed. The goal of this system is to obtain more precise and accurate results regarding the placement, size, and quantity of defects on each sample before the rolls continue in the production of becoming microelectronic devices.

Keywords: Thin Film, Roll to Roll, Flexible Substrates, Defect Detection, Microelectronics Manufacturing

1. Introduction

Roll to Roll manufacturing is a process consisting of depositing and patterning material on a single sheet of thin flexible material. The goal of Roll to Roll Manufacturing is ultimately to reduce costs and make the process automated to produce higher throughput. A main purpose of the research done at the CAMM Lab is to find ways to show Roll to Roll manufacturing's feasibility in real world manufacturing. Thin film manufacturing is critical to emerging technologies in fields including, but not limited to, military, medical, and flexible electronics. However, the process can produce defects, contamination, and material degradation, making portions of the roll unusable. In order to ensure quality control, it is necessary to have in-line defect detection (Binghamton University, 2010).

1.1 Background

Some examples of a few technological fields that can be pushed forward by Roll to Roll processes are flexible displays, flexible photovoltaics, fuel cells, and thin-film batteries (Department of Energy). The majority of focus for the scope of this project is in flexible electronics, but each field of use has unique quality standards that the flexible substrate must adhere to therefore making in-line defect inspection a key component. The thin films that are coated in various substrates, in these experiments Silicon Dioxide (SiO_2), can come with a number of internal defects like cracking, buckling, or uneven distribution of material. Despite being manufactured and processed in a clean room there are outside risks to the thin film substrates. The focus of this project is the detection of defects and contaminates, specifically dust and scratches upon the thin film substrates which have been manufactured. These defects have a range of sizes and a minimum of a few micrometers in size. Currently in the Roll to Roll manufacturing process there is optical inspection done by an operator. Though effective, it is time consuming and expensive. By automating the defect detection process, the operator could spend time doing value adding activities and ultimately reduce the overall cost.

1.2 Project Overview

The 2018-2019 team working on the Roll to Roll Inspection Platform is the third iteration of this team. Considering this, the team inherited a fully assembled roll to roll inspection platform, complete with the SunOptical Defect Sensor in a 3D printed case mounted inside of the inspection platform. This sensor takes pictures, which are then analyzed through the MATLAB code with the intent of identifying scratches and dust. Though the team was given code from the previous years, it was determined early on in the project that the code was defective, and that the system would work more effectively if the team developed new code to work with the SunOptical sensor. To that end, the team developed new MATLAB code that identifies scratches by comparing length and width. It determines which is longer and by what factor. Finally, it determines the size of dust scratches by analyzing the diameter of each of the more circular defects.

2. Methodology

2.1 Hardware

Dr. Gang Sun provided to the CAMM Lab a SunOptical Defect Sensor, which has been handed down for the purpose of this project. The SunOptical Defect Sensor has two lenses that give a combined single output and three colored lights consisting of two red toned lights, one blue, and one green. In addition to the sensor there is also a SunOptical Spectroscopic Reflectometer that will be used to determine certain characteristics of the roll being tested, specifically thickness. The results found using the SunOptical Defect Sensor will be verified using the Keyence Confocal Microscope touched upon in Section 3.1. The CAMM lab also provides a Dell Desktop Computer which contains the necessary software packages. The Roll to Roll Inspection platform is centered around the Energy Conversion Devices and Integral Vision In Line Defect Inspection Tool, which is the conveyance system that unwinds and rewinds the thin polyimide film, although, the system can also be used for other thin materials like thin flexible glass or Polyethylene Terephthalate (PET). The SunOptical Defect Sensor is made of two cameras and four LED lights. The two lens that are on this sensor are the two cameras. One is a low-resolution high-speed camera and the other is a camera that can take 1920x1080 pixel pictures. Both of these have specific magnifications on each respected lens. The four LED lights are laid out on the rest of the semi-circle design of this sensor. This is all done so both cameras and all four lights are based on the focal point. The colors of these lights are two red, one green and one blue. They work independently of one another and can be adjusted to increase and decrease brightness of each, which is done all on the Windows Machine.

2.2 Software

The software packages necessary for controlling the SunOptical Defect Sensor and SunOptical Spectroscopic Reflectometer were preinstalled on the Dell Desktop computer in the clean room. The Raspberry Pi controls the sensor through Python coding that has a preset instruction. The only user input that varies is the speed at which the roll has been preset to move at, the length of time, and the light colors needed. The user also inputs tension needed for the roll to unwind, diameter of the roll, and speed for the Energy Conversion Devices & Integral Vision (ECD-IV) In Line Defect Inspection Tool through the user interface. The user inputs for both interfaces should match to ensure accuracy. In addition, the team has created a photo inspection and analysis code using MATLAB to take the output from the Python code and obtain usable data, which will be described in detail in section 2.3.

2.3 Image Conversion

The Image Conversion process is completed using the MATLAB Image Processing Toolbox. Images are captured using the SunOptical Defect sensor and its respective RGB color reflection. The images captured by this sensor are then stored on the Windows machine where the MATLAB code is run. Using the Image Processing Toolbox, each image is converted into a binary image, seen in Figure 1, where white coloring corresponds to defects and black coloring corresponds to the non-defective roll.

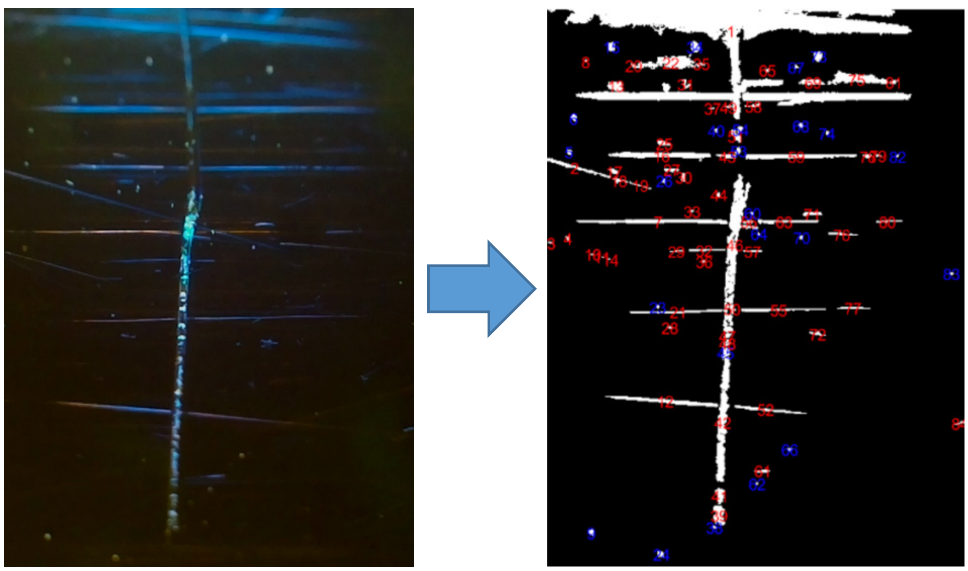

Figure 1. Binarization of Sensor Images

In the left image of Figure 1 was directly taken by the SunOptical sensor under a combination of blue, green, and red light. There are exaggerated scratches intentionally made along the film for proof of concept. This image was then saved on the computer and analyzed using the MATLAB software, rendering a binary image, shown on the right, with scratches identified in red and dust particulates identified in blue. Categorizing defects into dust and scratches is based on the ratio of the maximum and minimum axis of the defects. Meaning that scratches will have a higher ratio. The right of Figure 1 has the post-processed binary image. This information can be seen visually in Figure 2. Each color from the original image is analyzed, and any pixel over a luminance threshold on 0.2 was converted to white while any pixel below that threshold was converted to black. This threshold value was determined through various trials to determine the most accurate value.

2.4 Sampling

Sampling will be completed by using the Roll to Roll inspection platform that has been developed. To obtain these samples, the roll will be fed through the inspection platform at a user inputted speed. As the roll is fed, the user then inputs the speed of the roll, and a length of time for the roll to be ran into the Windows Machine via the python coding software. The sensor begins taking these pictures which are stored in a folder. The MATLAB code pulls these images, and analyzes them as explained in section 2.3. There is a table created which summarizes the details of each defect. The output of the MATLAB code also provides an image which shows the scratches and dust particles. Each defect is numbered and shown on the image, so the location of each detect is known. An output with information regarding the overall defects such as the overall percentage of the image that is defective, the amount of scratches, and the amount of dust particles is given. Lastly, a histogram is created which summarizes the size and number of defects for each sample. The team tested 37 samples as 30 is the required number of samples needed for the Central Limit Theorem to ensure we are confident in accepting or denying a roll due to it being defective or non-defective.

2.5 Vibrations

Vibrations information was taken using a Vernier 3-Axis Accelerometer, which has an accuracy of +/- 0.5 meters per second squared in conjunction with a Vernier DAQ, and the Logger Lite software (Vernier, n.d.). Data was collected when the machine was actively running and when the machine was off. This was done to determine if potential vibrations were due to the running of the machine or if they were due to environmental effects. For these four samples, vibrations were minimal, near the stated margin of error of the accelerometer, and did not have a negative effect on the clarity of the images received from the defect sensor. It was concluded that the mount would not be redesigned. Samples were taken with both heavy stomping and striking the frame of the machine to represent over exaggerated movement within the lab. During these measurements, more significant vibrations were present. However, since this only occurred when the machine was physically struck or there was heavy stomping, it was determined to not be a cause for concern in this environment. If vibrations were to be over the determined threshold, this would interfere with the ability of the sensor to take clear images. This would create difficulty in determining how many defects and the size of each defect upon a sample. The threshold for the vibrations on an inspection platform is dependent upon which industry will be using these thin film substrates, as well as the camera used to take images of the sample.

3. Results and Discussion

3.1 Verification

Verification will be done using the Keyence Confocal Microscope at the Smart Electronics Manufacturing Lab at the Innovation Technologies Complex at Binghamton University. This machine is known to be accurate to micrometer lengths. The accuracy of the MATLAB code and the inspection platform will be checked against this. The depth, major axis length, minor axis length, and depth for the scratches for 40 samples. The difference between major axis length and minor axis length will be used to determine what counts as a true scratch or is simply just dust. Currently, a defect is considered to be a scratch if the major axis length is more than twice the minor axis length. Finding not only the total area of the scratches will show if the MATLAB code is able to output the correct size of scratches, determine the difference between scratches and dust, and if there are obvious scratches that the MATLAB code is not picking up. If the code is inaccurate, this will allow for a correction to be added to account for the discrepancy.

3.2 Results

By utilizing the SunOptical Defect Sensor the process for detecting defects on thin film substrates has become essentially automatic. The output of the Roll to Roll Inspection process displays details regarding the size of each defect whether it be a scratch or a dust particle as well as the percentage of the sample which is defective. In the samples the team has tested, most rolls had only particles of dust. The output for the size of dust particles and the percentage of the image that was defective was successful through utilization of the MATLAB code. There was one scratch in the batch of samples tested and the size was verified using the Keyence Confocal Microscope. Therefore, the team has deemed the Roll to Roll Inspection Platform to be successful in its purpose. The team had one over exaggerated sample with many scratches on it and this sample was also successful when it was processed through the Roll to Roll Inspection Platform and output the required histogram, details of the defects, and the percentage of the image which is defective. This sample was not verified using the Keyence Confocal Microscope because it was from a previous team's saved images and this year's team did not have that physical roll to test.

The MATLAB code outputs scratch assignments and measurements regarding the length of scratches in a spreadsheet, however, it is best understood when shown visually. Figure 2 below shows the distribution of defects found in the sample image shown in Figure 1. While there are many defects shown in the zero to 500 micrometer range, many of them would be considered dust or contamination. There are significantly less defects larger than 500 micrometers in length, which would be typical of a scratch or large fiber contaminate. The blowup of the larger sized defects found from the sample in Figure 1 confirms that the MATLAB code can detect various sizes of defects.

4. Conclusion and Future Research

Thin film manufacturing is one of the first steps in the process of creating microelectronic technologies such as wearable electronics, flexible electronics, smart lighting, wireless charging, transparent displays, and many more. While the testing of complete devices is the most definitive mean to ensure the device will work, it is vital for inspection to be included as a step throughout the manufacturing of microelectronics. Testing for defects throughout the manufacturing process may add time to the process, yet it helps reduce costs in the overall production (Read & Volinsky, 2007). For each type of microelectronic technology there can be different thresholds for how many defects are acceptable for the thin roll to pass into the next step of production. The inspection of thin films is the first area after the manufacturing of thin films in which it is decided which rolls can continue into production and which rolls are not usable. The process of scratch detection verification

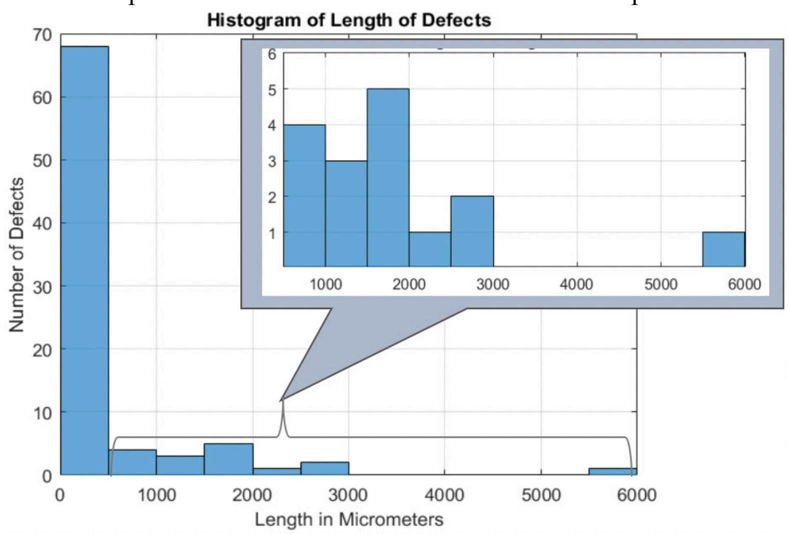

Figure 2. Histogram of Defects Detected from Image in Figure 1

is as follows: scratches are intentionally made in the film and sample pictures are taken of the affected areas and analyzed using MATLAB software. This defective film is then put through the analytic process in the Keyence lab, and the results of these two processes are compared for accuracy. However, before sample images with intentional scratches were taken, mechanical issues occurred in the sensor such that it had to be sent off site for troubleshooting and hardware repair. Due to these unforeseen issues, the process of scratch detection has not yet been verified. However, before the sensor became inoperable, samples were taken by the sensor that showed zero defects. This absence of defects was able to be verified using the described process, thus offering some verification of the detection process. Once the sensor is repaired, the process of scratch detection will be verified utilizing the aforementioned defect detection verification process.

Within the inspection platform as a whole, there is an ability for the rolls to be characterized by their index of refraction, thickness, and roughness. This can be done by utilizing various types of sensors such as the Spectroscopic Reflectometer and the Roughness Sensor, both provided by SunOptical Systems. To gather these characteristics a MATLAB code would have to be written to analyze the images taken by both of these sensors. Through further research and analysis, it is possible to have this data and for the system to output a report with this information. Due to the limitations of the current MATLAB code and the ability of the sensors with the current rolls, the team is currently not characterizing the rolls with these characteristics. Alternatively, the team is focusing on the defect detection on each image gathered from the roll.

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